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# Registration Process of Laser Scan Data in the Field of Deformation Monitoring

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**Abstract**

Terrestrial laser scanning is a new method for monitoring the deformation of complicated objects. In contrast to the classical technology, no discrete identical points are available to compare. This problem can be solved if parts of the point cloud are grouped and the points in these groups are seen as representatives of a parameterized surface. An example for such a proceeding is the use of target spheres for the registration of scans. The radius of the spheres is known and the centre point coordinates can be calculated by a best-fit algorithm. These coordinates can then be introduced in a classical transformation calculation using identical points. However, such an approach has crucial disadvantages. First, it is necessary to use artificial targets and it can be of high effort to place these targets. Secondly, only a very small part of the redundancy contained in overlapping scans is used for the calculation. The resulting accuracy of the orientation parameters is therefore often not sufficient for detecting deformations. In this study, we compare scans of an object, where the possible deformation is in the order of the measurement noise. For that reason registration of point, cloud data is of great importance. The accuracy of different methods for registration and co-registration is presented.


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*Keywords:* Terrestrial laser scanning; deformation monitoring; registration process.

## Introduction

The registration process in the field of laser scanning measurements begins with bringing the data into one common coordinate system. In most cases, it is necessary to scan the object from more than one scanning station. In this case, it is necessary to bring the data into one common coordinate system. In case of deformation monitoring,

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the scan data must be in the same coordinate system to make comparison between different epochs.

In deformation monitoring applications, the orientation of measurement data is a crucial point. Laser scanner point clouds can be registered using surface based algorithms, such as ICP (iterative closest point), LS3D, automated generated targets (planes) or using algorithms, which are based on discrete points. This paper offers a number of conceptual possibilities with regard to quality, automation and capability.

The theoretical evaluation of the accuracy which can be obtained from laser scanning data is a quite complex problems, because it depends on metrological aspects of the adopted instruments (Ingensand, 2006), on georeferencing (Gordon & Lichti, 2004), on the material (Lichti & Harvey, 2002) and on the incidence angle of laser beam to the surface of scanned object. Considering results reported in literature, errors from the latest two factors are difficult to quantify. For a preliminary analysis, uncertainty errors from measurements and geo-referencing are included. The expression of the uncertainty for a scanned 3D point can be evaluated as reported from Scaioni (2005):

$$C_x = J_{geo} C_{geo} G_{geo}^t + J_{\text{int}} \mathrm{C}_{\text{int}} G_{\text{int}}^{\mathrm{t}}; \quad (1)$$

where $\boldsymbol{C_{geo}}$ is the covariance matrix of geo-referencing parameters and $\boldsymbol{C_{int}}$ that of measured quantities. In the covariance propagation formula $\boldsymbol{J_{geo}}$ and $\boldsymbol{J_{int}}$ are derivative vectors derived from geometric relations to transform geo-referencing parameters and intrinsic measurements into 3D point coordinates. The expression of $\boldsymbol{C_{geo}}$ depends uniquely on the geometric position of Ground Control Points and on their uncertainty, so that a preliminary estimate of it could be carried out for each scan. Covariance matrix $\boldsymbol{C_{int}}$ can be evaluated as follows, considering the standard deviations of measurements (range $\sigma_\rho$, horizontal and vertical angles $\sigma_\alpha$ and $\sigma_\theta$) and the laser beam cross-section $\delta_b$:

$$C_{\text{int}} = diag\left(\frac{\sigma_\rho^2}{m}, \sigma_\alpha^2 + \frac{\delta_b^2}{16}, \sigma_\theta^2 + \frac{\delta_b^2}{16}\right). \quad (2)$$

where $m$ is the number of scan repetitions in case multi-scan is adopted.

## 2. Registration process

### *2.1. Usage of artificial targets*

In terrestrial laser scanning practice, special targets provided by the vendors, e.g., Zoller_Fruhlich, Leica, and Riegl, are mostly used for the co-registration of point clouds. As well as fieldwork time, accuracy is another important concern. Target-based registration methods may not exploit the full accuracy potential of the data. The geodetic measurements naturally introduce some error, which might exceed the internal error of the scanner instrument. In addition, the targets must be kept stable during the whole of the data acquisition campaign. This might be inconvenient when the scanning work stretches over more than one day. On the other hand, one important advantage of the target-based methods should not be ignored. Targets are essentially required in projects where the absolute orientation to an object coordinate system is needed.

There are some inhomogeneity-based reasons for loosing processing time and qualities (Milev, 2010). First inhomogeneity reason is influencing the registration process. In the case of point clouds it is not defined which the point of the measurement is. Using a single point for the measurement position is random inside the measuring standard deviation of the scanner. It depended of the distance to the measured object. The points for the registration are typically not distributed in the maximal measuring distance of the scanner because otherwise it would be too big. This leads to an extrapolation problem outside the targets and to a decrease in accuracy. Second inhomogeneity reason are based on the distribution of the measured points. There is a straight connection between geometrical distribution of targets and accuracy. In this case, it is necessary to use artificial targets and it can be of high effort to place these targets. In many cases, it is impossible to place them geometrical correctly while also holding stable all the measuring company (Antova, 2015).

If the measurement task requires an absolute orientation of the laser scanner data control points have to be used in most cases. It is of particular interest how accurate the control points can be detected. The scanner software is able to measure the target center with mm-accuracy applying an intensity-weighted centroid operator on multiple points covering the target. The deviations between target and actual shift are 1 mm in plan direction and 3 mm in Z direction (Shneider 2006), which shows that signalized points can be measured at a precision much better than single point precision, with the planimetric coordinates better than the depth coordinate. However, this test is made on targets, which are measured in a more accurate way than other scanned points.

### *2.2. Automated generated targets – can be planes in overlapped scans but also another surfaces*

The method follows the region growing approach for extracting planes. First, in each point an initial normal vector is estimated from its neighbors by fitting of a plane.1. Points with a large r.m.s. are discarded from the beginning, because they are more likely to be single points, or on surfaces with a very small extent. Planes are grown, starting with the initial normal vector and position of the seed point. Neighbouring points are accepted if they are:

- below a threshold distance to this plane, and
- the angle between plane normal vector and initial normal vector is below a threshold.

After adding a point, the plane is determined anew by adjustment of all accepted points. If no more points can be added to a segment, the next segment is initiated with a new seed point. In the segmentation algorithm, but also in later steps of deformation analysis it is necessary to find a mathematical parameterization for planar patches (e.g., segments). The model parameters xˆ =f (a,b,c) for the planar model x a + y b + c = z and the model residuals eˆ can be found.

Automated plane detection based registration (Milev, 2010) is done separately for each scan in the corresponding image matrix. Rows and columns of the image matrix represent the discrete vertical respectively horizontal angles of the points in the coordinate system of the scanner. Within an iterative process the image matrix is split into sub matrices. After each iteration step an adjusted plane is calculated approximating the points contained in the resulting sub matrices. The iteration process continues as long as a sub matrix stays planar or the stop criterion is reached (Gielsdorf et all. 2008). The identical planes in each scan pair are used for an automated registration process There are two criteria which have to be fulfilled for accepting a group of points to be planar, both resulting of the plane adjustment. The first criterion is the estimated standard deviation of a single point and decides if the point group is planar. The second criterion is the estimated standard deviation of the top of the normal vector. This value is used as decision criterion if the adjusted plane can be seen as significant or not. This method raises the productivity and decrease the time for the registration approximately 3 times and works proper in ~70% of the tested overlapped scans. The degree of success is based on the overlapping factor. Including free form surfaces in the registration model the success quota is rising to 90 %. A free form surface modeling is a precondition for this. Using the combination planes, surfaces, lines and points, the automated registration quota is 100%.

### 2.3. *Iterative Closest Point Method*

Comparison of different scans can be made possible by transforming them into one superior coordinate system. For this purpose the Iterative Closest Point (ICP) method could be used. It works on two scans, transforming the point cloud of the second scan into the coordinate system of the first. In the implementation used, the corresponding (closest) point in the first scan is computed for every point of the second scan, and the distance within each point pair is used for sorting the correspondences. The correspondences with the shortest distances, specified by a fixed percentage, e.g. 20%, are used to determine the six transformation parameters (shift and rotation) for minimizing the distance between corresponding points. Iteration end is declared, if the sum of squared distances does not become smaller anymore. In (Lindenberg, 2005) for each point p in scan 1 its normal np is computed by determining an adjusting plane through some neighbouring points of point p in scan 1 and taking its normal. For a point b in scan 2 the closest point in scan 1, say point a, is searched. The projection of the difference vector b-a on the normal can be built. This vector indicates for each point the direction of movement and its magnitude. This procedure can be applied to all points, and if the length of these vectors is random throughout the entire data set it indicates as stationary. Otherwise, groups of nearby vectors with similar direction and length indicate movement of objects between the epochs. This procedure can be applied favorably to segments. For this method, it is not necessary that two scans were taken from the same position. However, they have to be in the same coordinate system.

### *2.4. Least Squares 3D Surface Matching*

A method for the automatic co-registration of 3D surfaces is presented in (Akca, 2010). The method utilizes the mathematical model of Least Squares 2D image matching and extends it for solving the 3D surface matching problem. The transformation parameters of the search surfaces are estimated with respect to a template surface. The solution is achieved when the sum of the squares of the 3D spatial (Euclidean) distances between the surfaces are minimized. The parameter estimation is achieved using the Generalized Gauss-Markov model. Execution level implementation details are given. Apart from the co-registration of the point clouds generated from space borne, airborne and terrestrial sensors and techniques, the proposed method is also useful for change detection, 3D comparison, and quality assessment tasks. The current implementation uses a 3D similarity transformation model for the geometric relationship. The unknown transformation parameters are treated as observables with proper weights, so that sub-versions of the 7-parameter model can be run, i.e., rigid body (6-DOF), tilt and translation (5-DOF), translation (3-DOF), horizontal shift (2-DOF), and depth (1-DOF).

## 3. Conclusion

The surface based registration techniques stand as efficient and versatile alternatives to target-based techniques. They simply bring the strenuous additional fieldwork of the registration task to the computer in the office, at the same time optimizing the project cost and duration, and achieving a better accuracy. In the last decade, surface-based registration techniques have been studied extensively.

The standard deviation of the registration resulted is 2.1 mm, which is 4 times better than the single point accuracy. This value, however, indicates a limitation for the detectability of absolute deformations. Registration algorithms based on surfaces instead of targets– applied on surfaces in the non-deformation area – might have the potential to increase the registration accuracy beyond this value (Shneider 2006). Leica claims an accuracy of 6mm at 50m for the Leica HDS2500. Analysis of plane fitting to segments lead to a measurement noise of 3mm.

More experiments are planned to study the importance of the key factors that drive the performances of the procedure (configuration of the scene, stable vs. deformation areas, sensor-target distance, sampling density, response of the different targets, etc.) and to increase the flexibility of the technique. Finally, it is worth underlining that other registration algorithms, e.g. those based on Iterative Closest Point algorithms, and implemented in commercial software packages (e.g. Cyclone, Geomagic, PolyWorks) could be used to perform the deformation analysis in a way similar to that proposed in this work. It might be useful to compare the performances of these algorithms using a deformation test study.

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